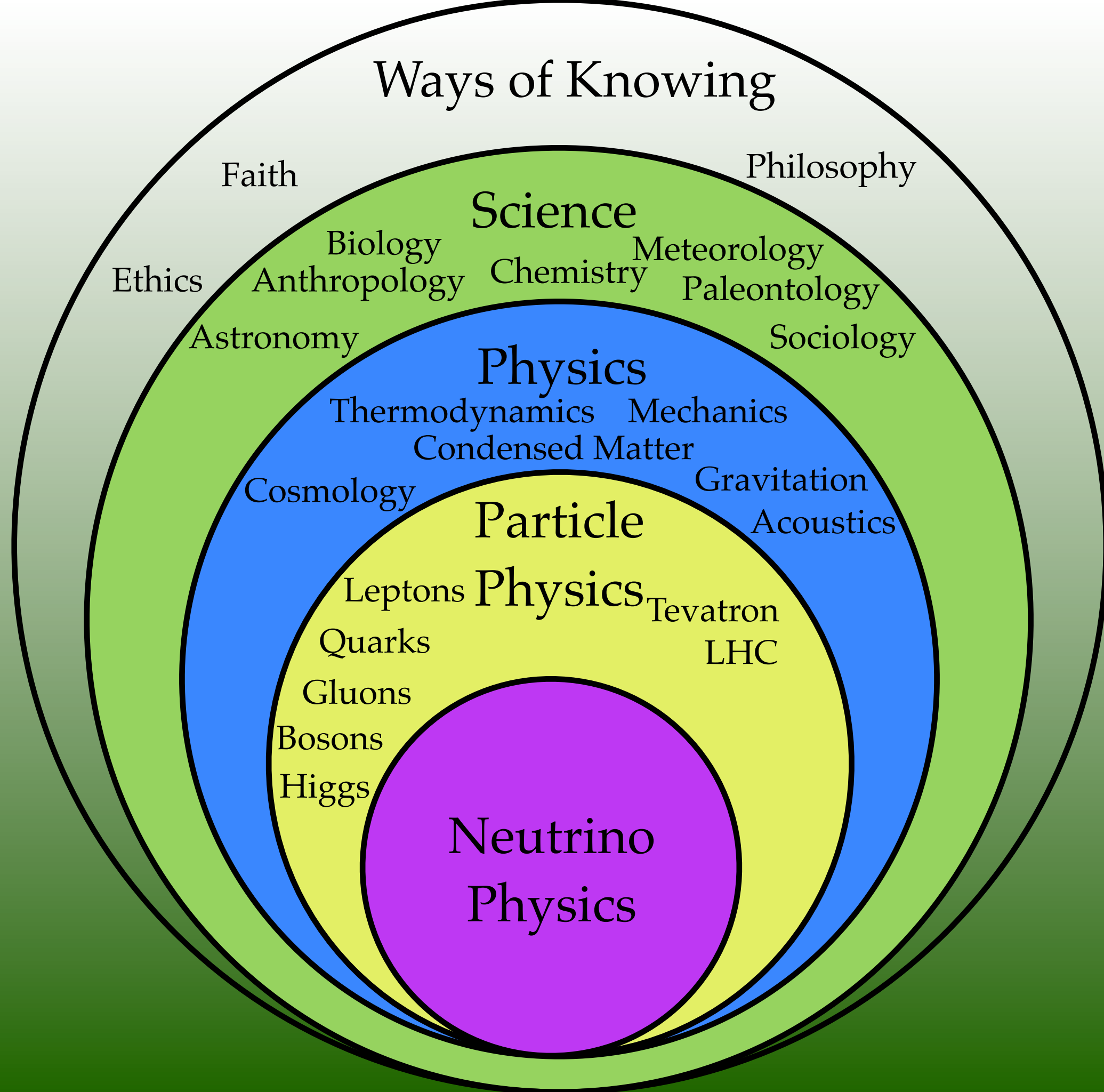


Neutrinos

The Little Particles that Could!

Luke A. Corwin
Indiana University
Ask-a-Scientist
Apr. 7, 2013



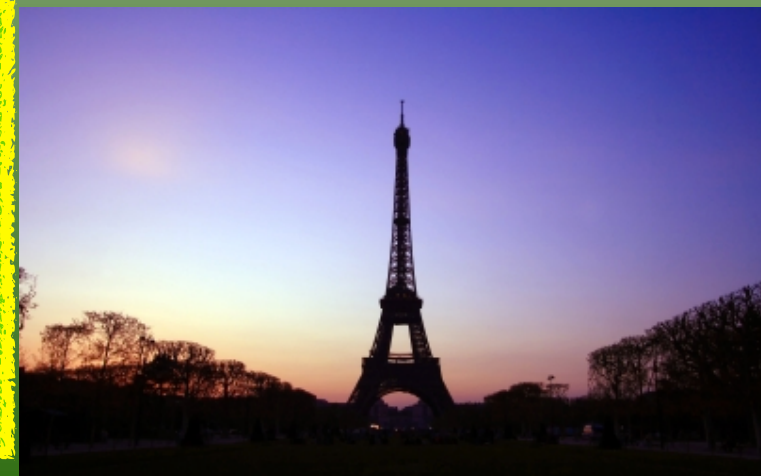
Science: The Basic Ideas

The laws of nature apply at all locations in the Universe, from your home to Paris to the most distant galaxies

These laws apply at all times from the Beginning to now and throughout the future

“... the **universality** and **immutability** of the fundamental **laws** is the basic postulate of all science.”*

Nature follows foundational laws that humans can understand.



* Quinn, H. (2007, January). “Belief and knowledge — a plea about language.” *Physics Today* Vol. 60, Iss. 1, pp. 8–9.

Science: The Method

“scientific method *n.* a method of procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses.”*

- *Ask a question
- *Formulate a hypothesis (testable answer)
- *Make a prediction
- *Test the prediction
- *Verify, Modify, or Reject Hypothesis
- *Repeat

Scientific Notation

[illegible]

*To express very large or small numbers, we use the notation

$$10^x = \underbrace{10 \times 10 \times 10 \dots \times 10}_{x \text{ times}} \qquad 10^{-x} = \underbrace{\frac{1}{10} \times \frac{1}{10} \dots \times \frac{1}{10}}_{x \text{ times}}$$

$$10^9 = 1,000,000,000$$

$$10^{-9} = 0.000000001$$

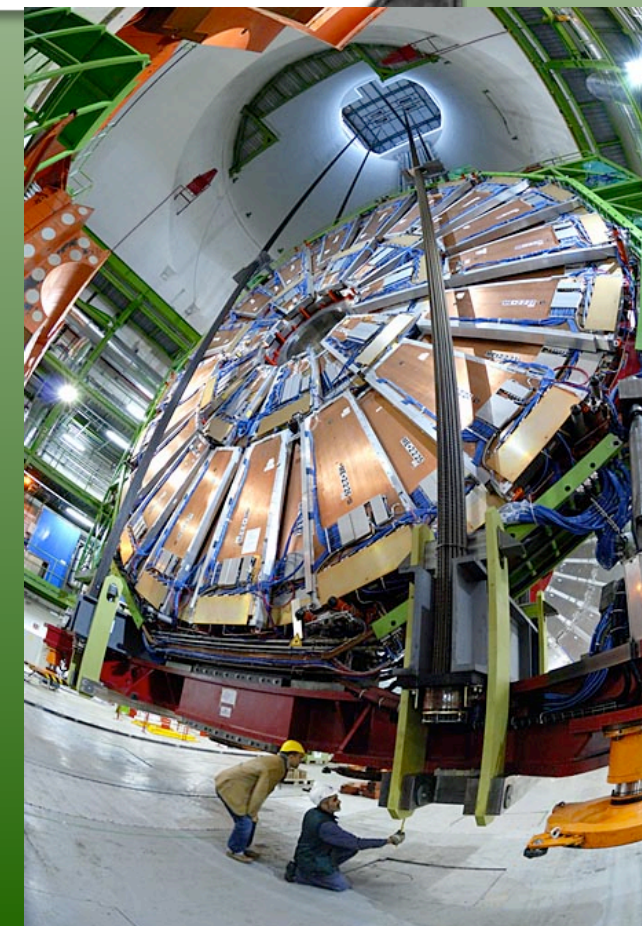
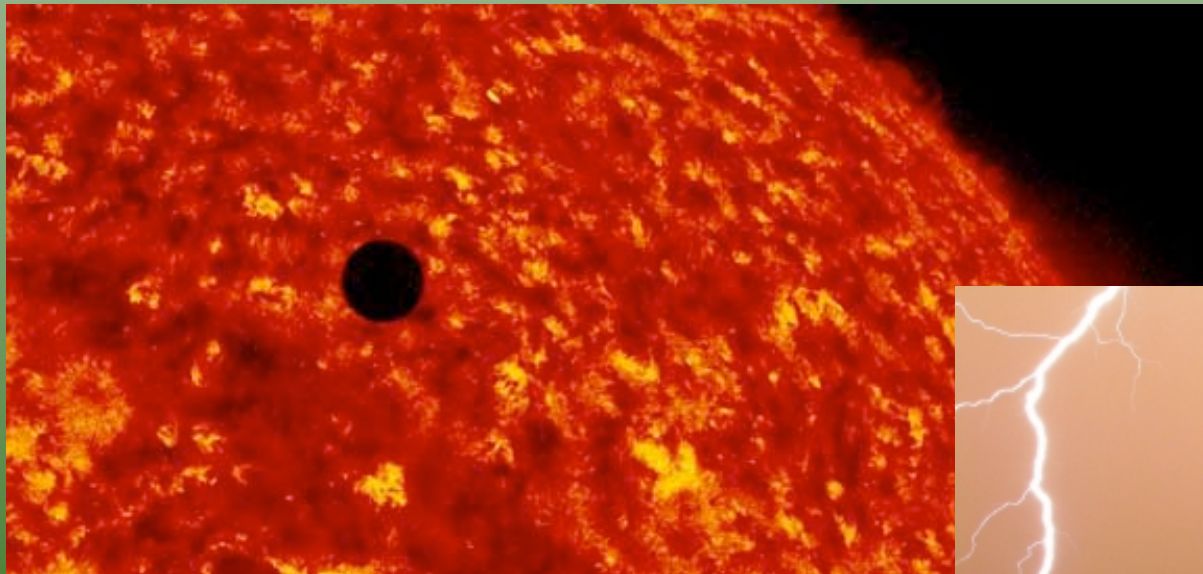
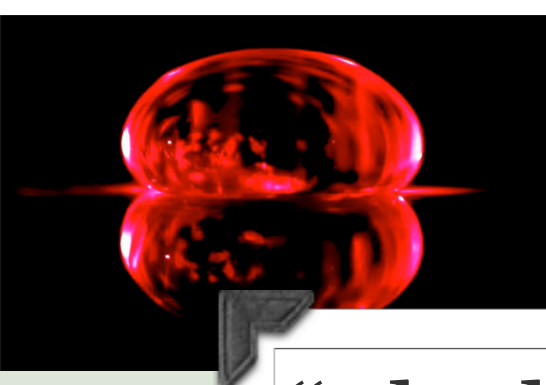
For Example

World Population = 7.08 billion = 7,080,000,000 = 7.08×10^9

Mass of a Proton = 1.672×10^{-24} g

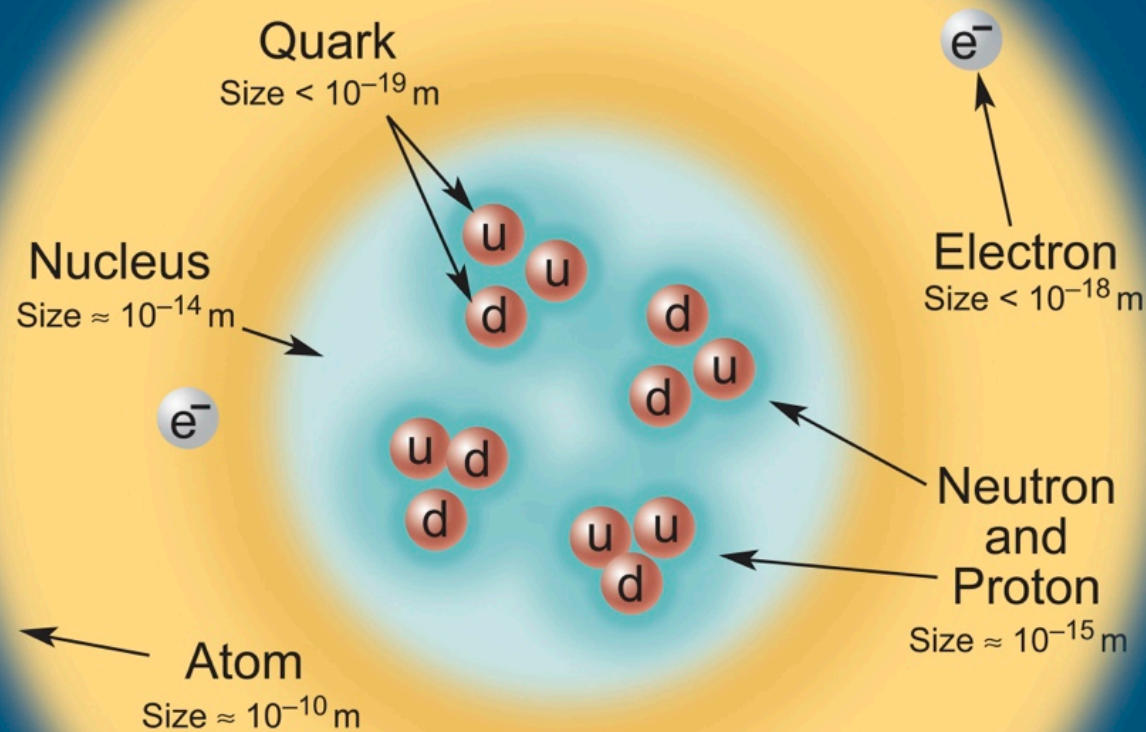
Physics

“The branch of science ... whose subject matter includes mechanics, heat, light and other radiation, sound, electricity, magnetism, gravity, the structure of atoms, the nature of subatomic particles, and the fundamental laws of the material universe.”*



Particle Physics

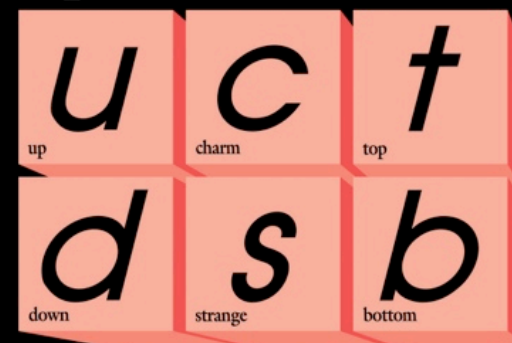
Structure within the Atom



If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

“What is the world made of?”
“What holds it together?”

Quarks



Leptons

Forces

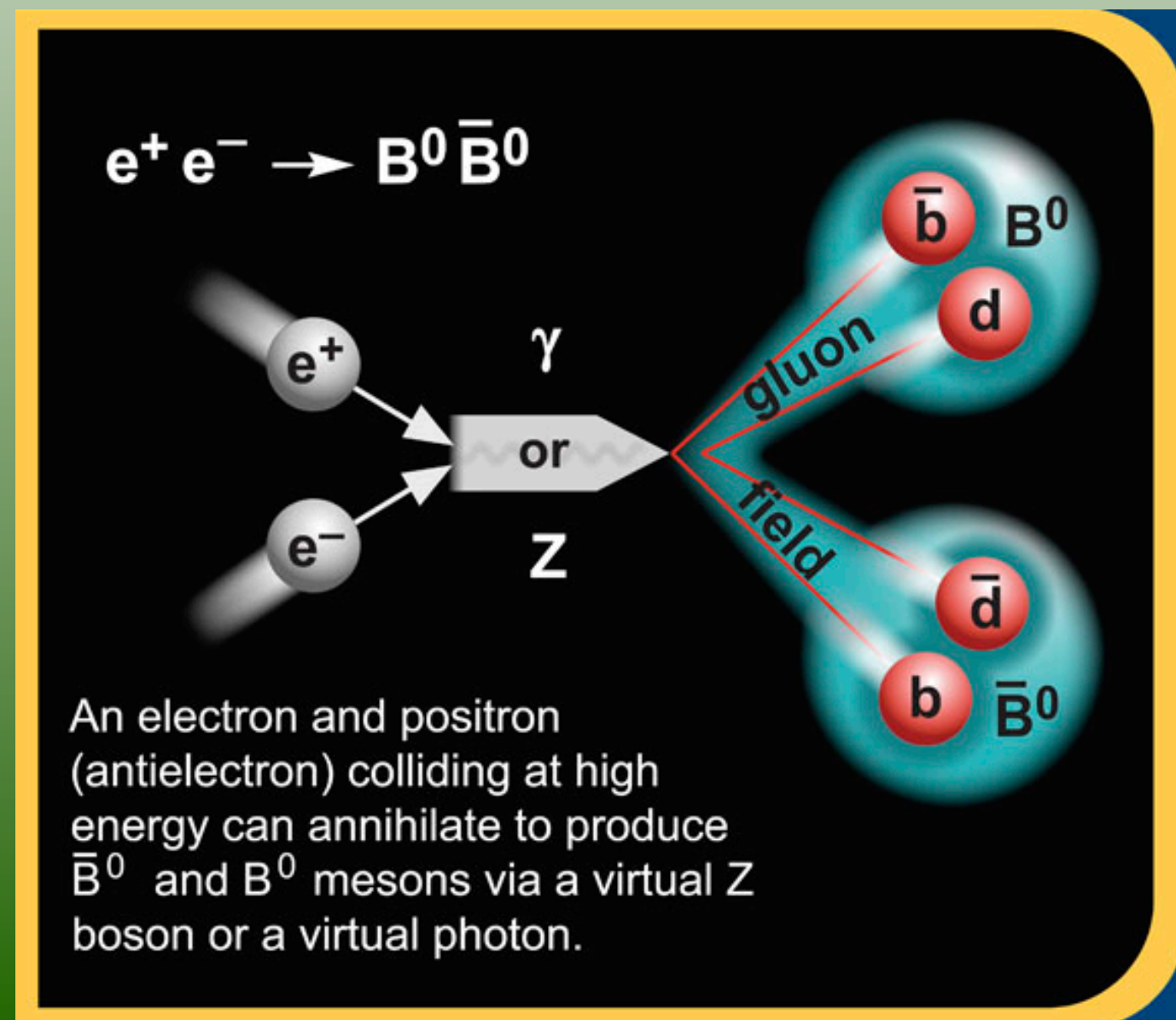


H
Higgs boson

Neutrinos!

Antimatter is Real!

- *Every particle type has an antiparticle
- *Antiparticles are denoted by
 - ★a bar over the particle symbol (e.g. d and \bar{d})
 - ★The opposite charge sign (e^+ or e^-)
- *Matter and Antimatter particles annihilate and produce new particles and radiation



Scales and Units

The scales involved in particle physics are well outside of our everyday experiences.

Welcome to the world of the very small...

The Speed of Light $c = 299,792,458 \frac{\text{m}}{\text{s}} = 670,616,629 \text{ mph}$

Energy

An electron volt (eV) is the amount of energy required to move an electron across a 1 volt potential.

$$1 \text{ eV} = 4.4 \times 10^{-20} \text{ kW}\cdot\text{hr}$$

Mass

Mass and energy are related by Einstein's $E=mc^2$, which means $m = E/c^2$.

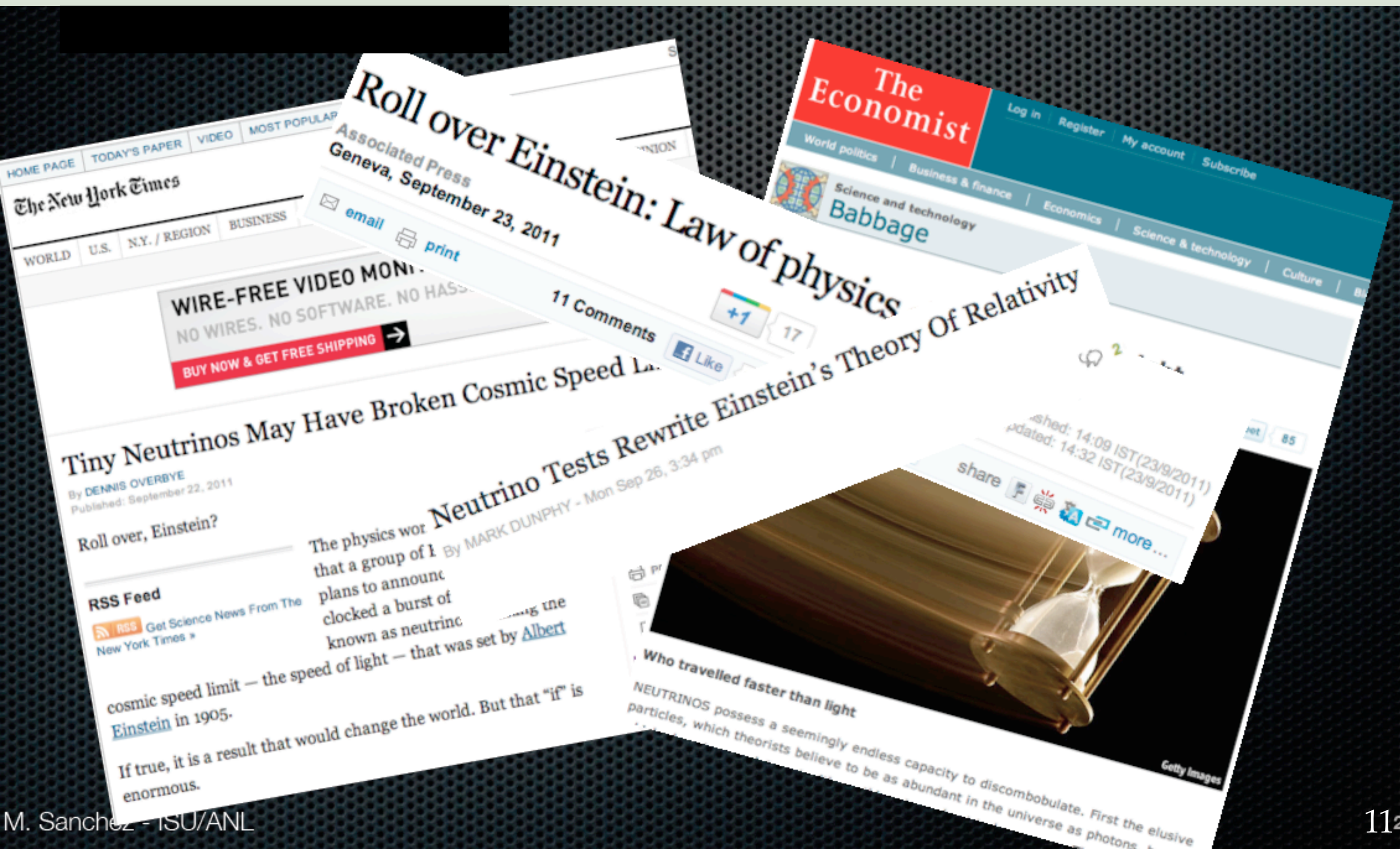
$$1 \frac{\text{eV}}{c^2} = 1.8 \times 10^{-33} \text{ g}$$

The mass of a grain of sand is about $2 \times 10^{27} \text{ eV}^2$

Could What?

- *Explain the “missing” energy and momentum of tritium beta decay!
- *Be very hard (but not impossible) to detect!
- *Come in three flavors!
- *Seem to change flavors as they travel!
- *Have very very little, but not zero mass!
- *Tell us about the foundational laws of the Universe!
- *Explain why we exist!
- *Have many more surprises in store!

Is there any evidence they travel faster than light?

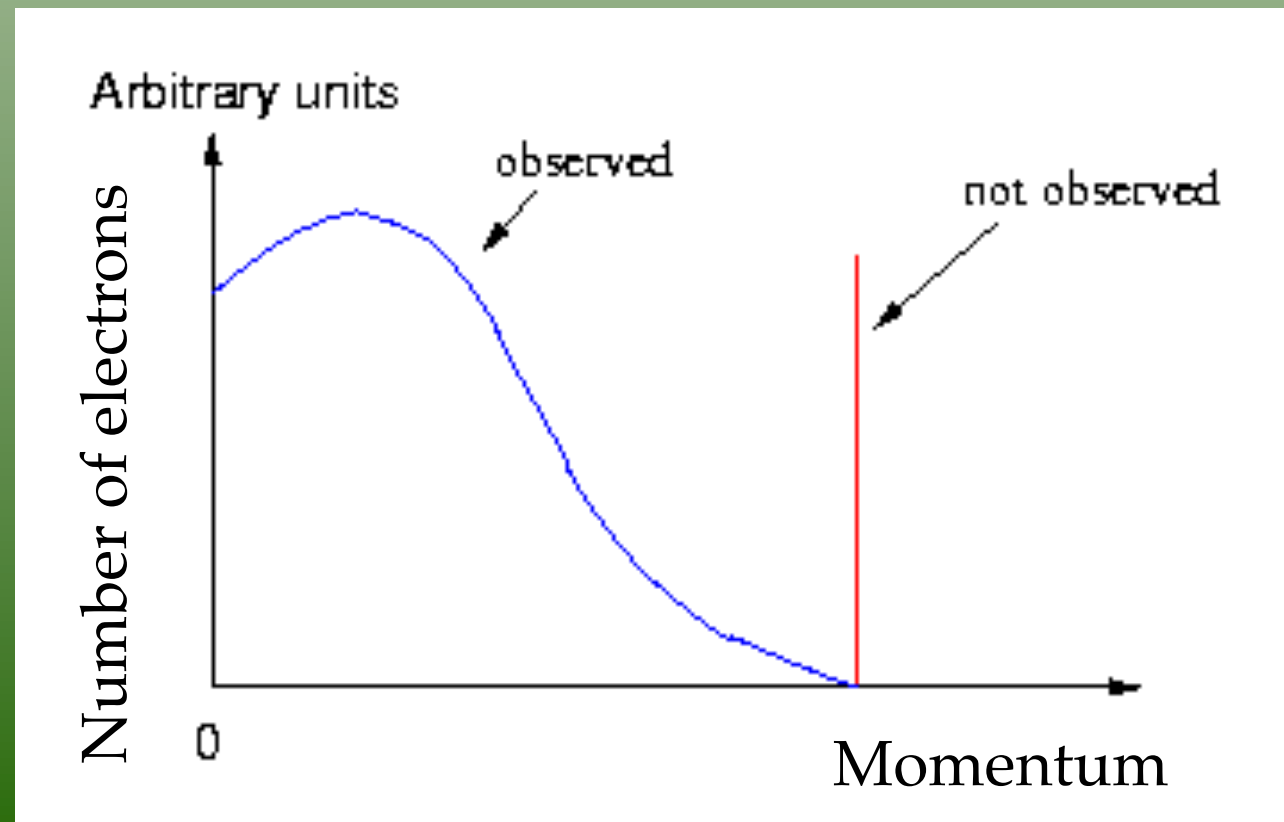
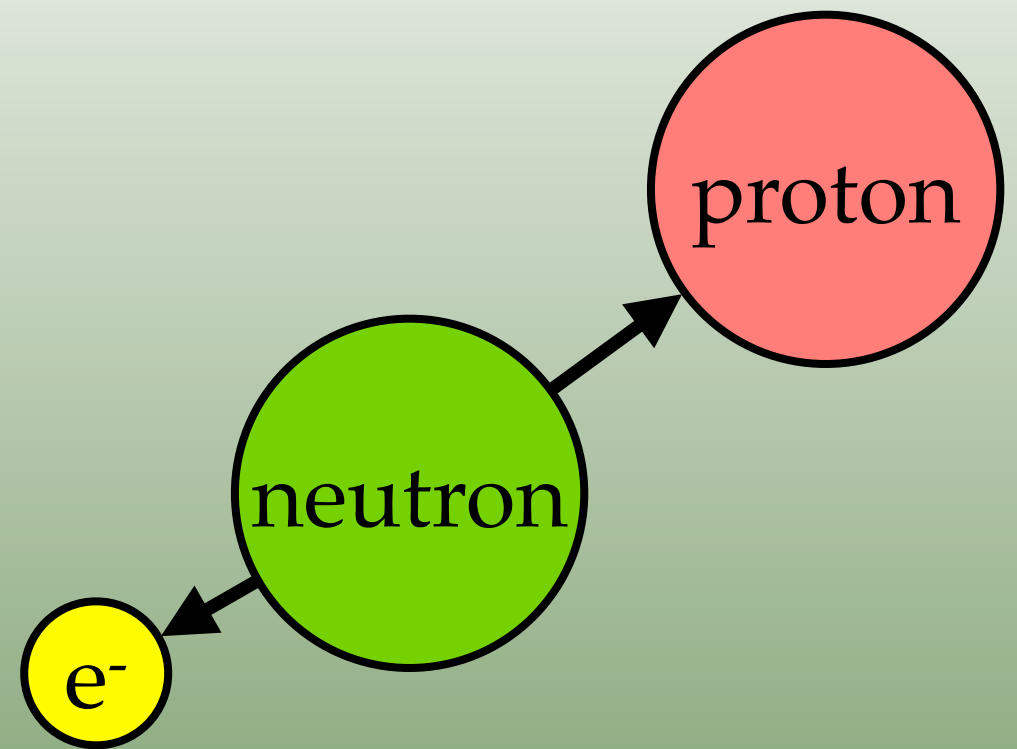


Is there any evidence they travel faster than light?



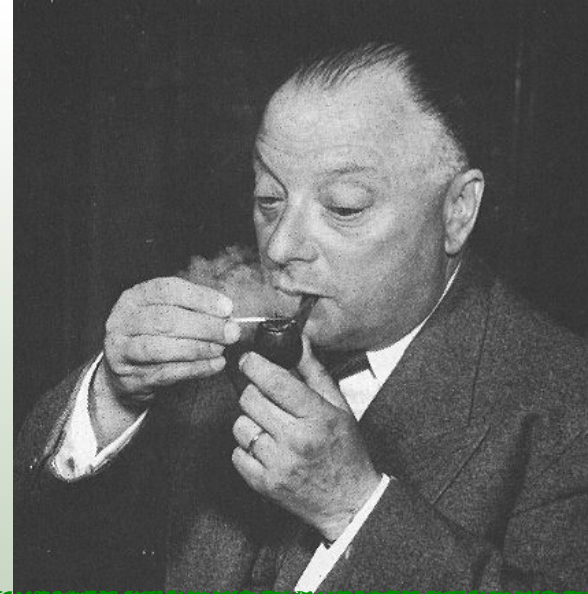
The Mystery of the Missing Momentum...

- *The scientific method in action.
- *Question: *Does conservation of energy apply at the subatomic level?*
- *Hypothesis: *Yes, it does.*
- *Prediction: *We can calculate the momenta of the decay daughters of a free neutron exactly.*
- *Test: *Measure the momenta.*



A New Hypothesis...

Dear Radioactive Ladies and Gentlemen,



Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

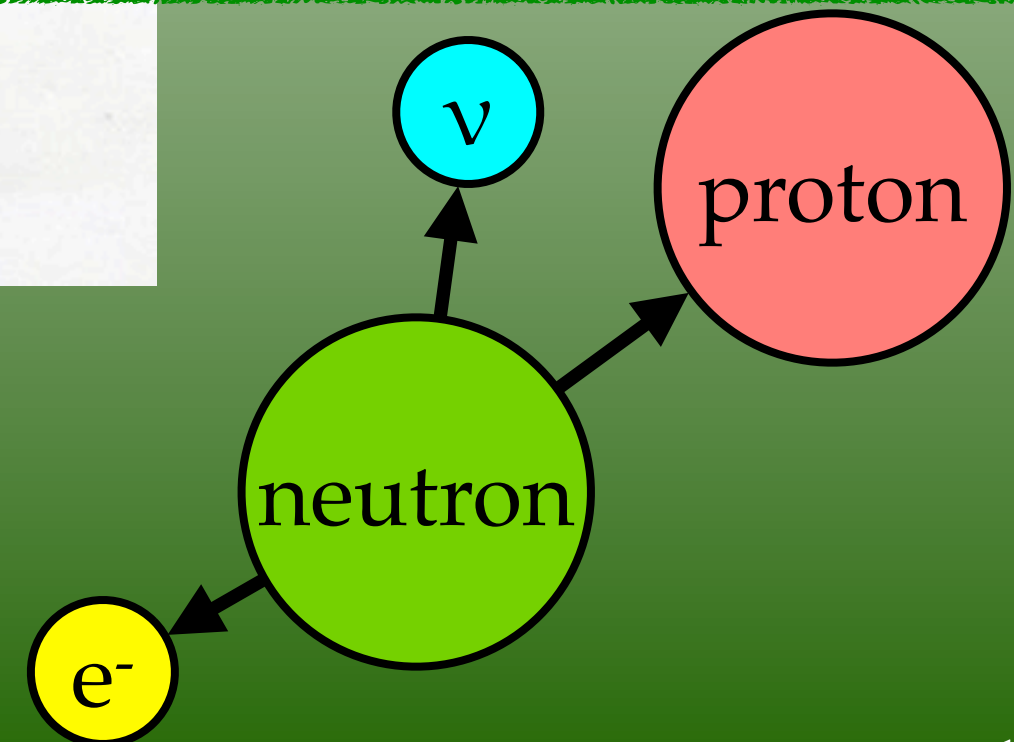
Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin $1/2$ haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta-Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

*Must be

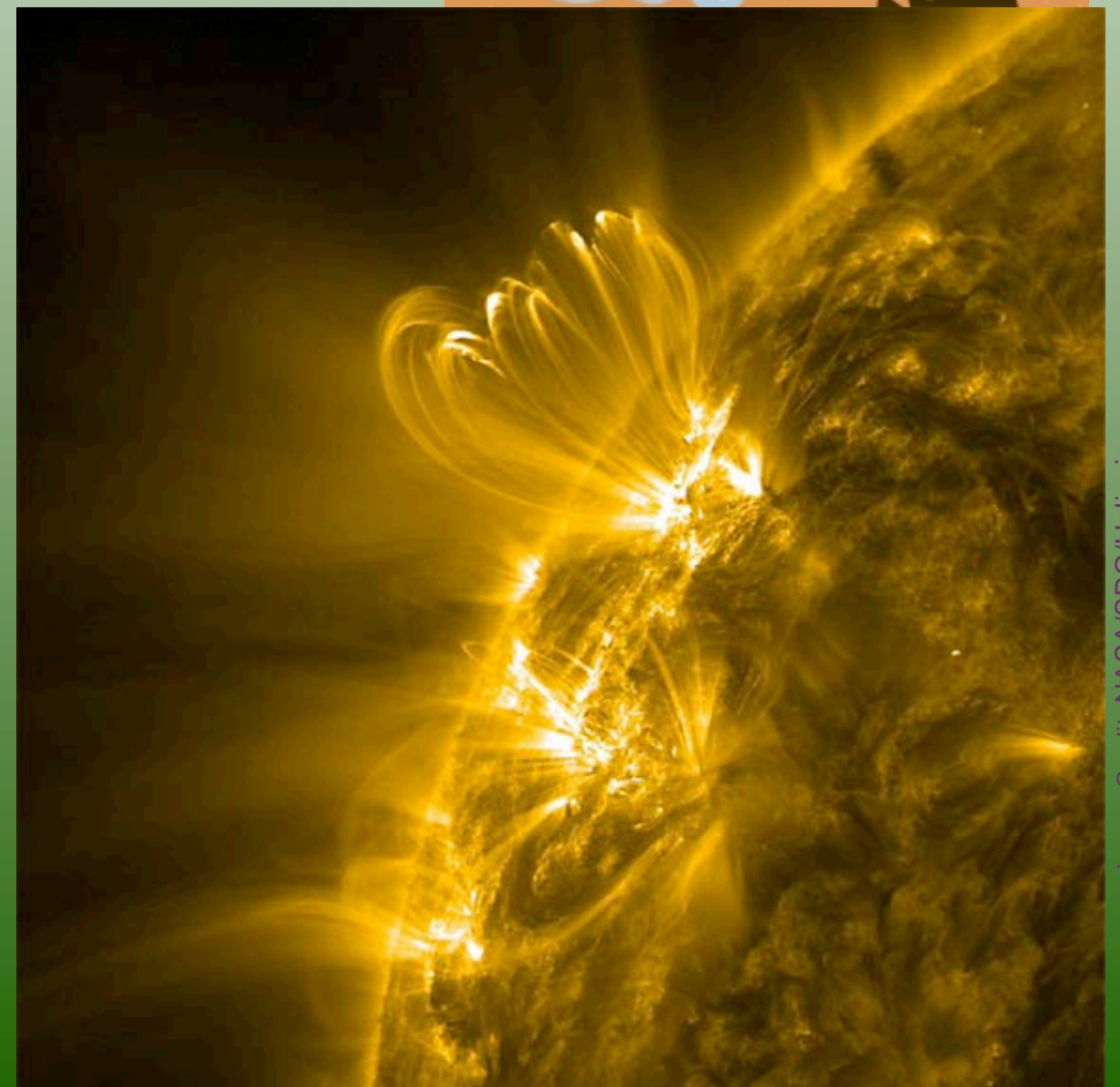
- ★Electrically neutral
- ★Weakly interacting
- ★Very light

*Dec. 4, 1930: Wolfgang Pauli proposed a new particle



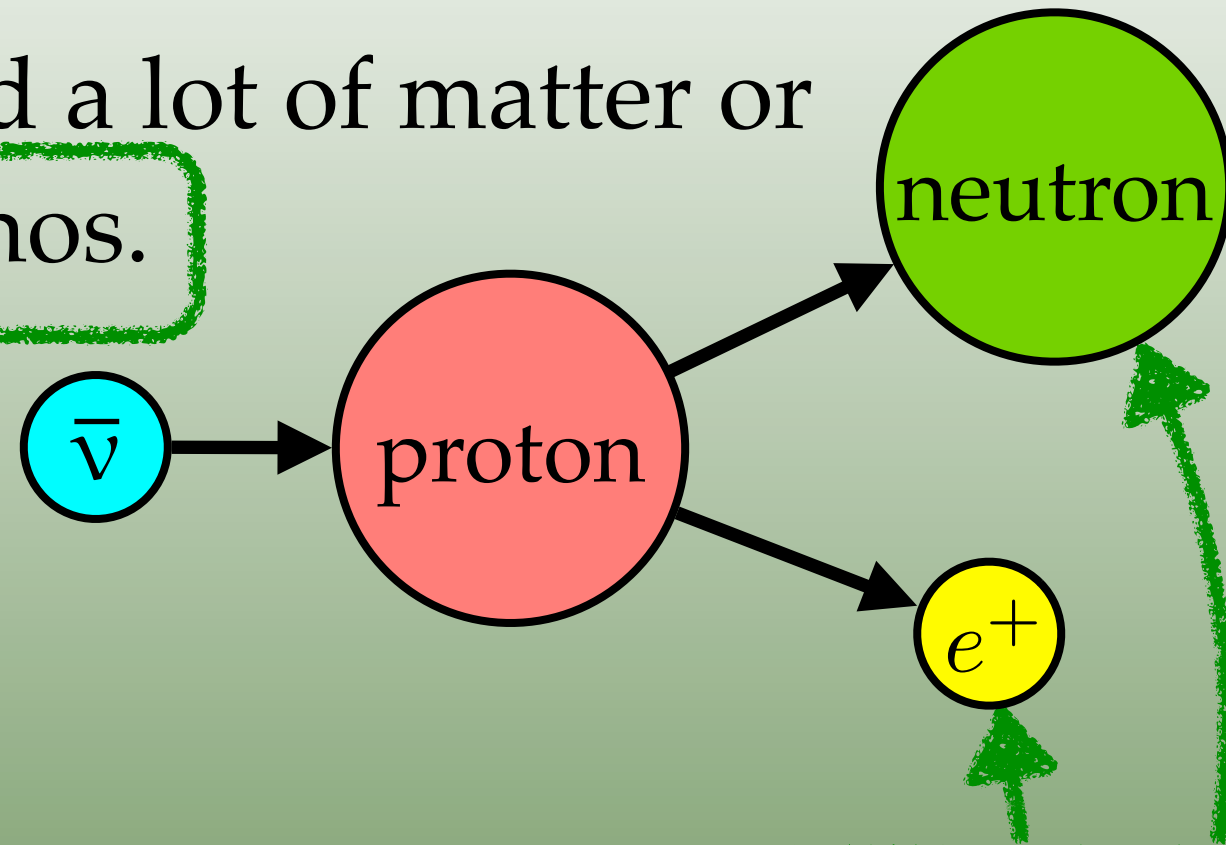
How Weak?

- *They can pass through a *light year* of lead and not hit anything!
- *About 50 trillion of them are passing through you ever second of every day from the sun, and you don't notice!
- *How do we find something so ghostly?



Two Guys and a Nuclear Reactor

*We either need a lot of matter or a lot of neutrinos.

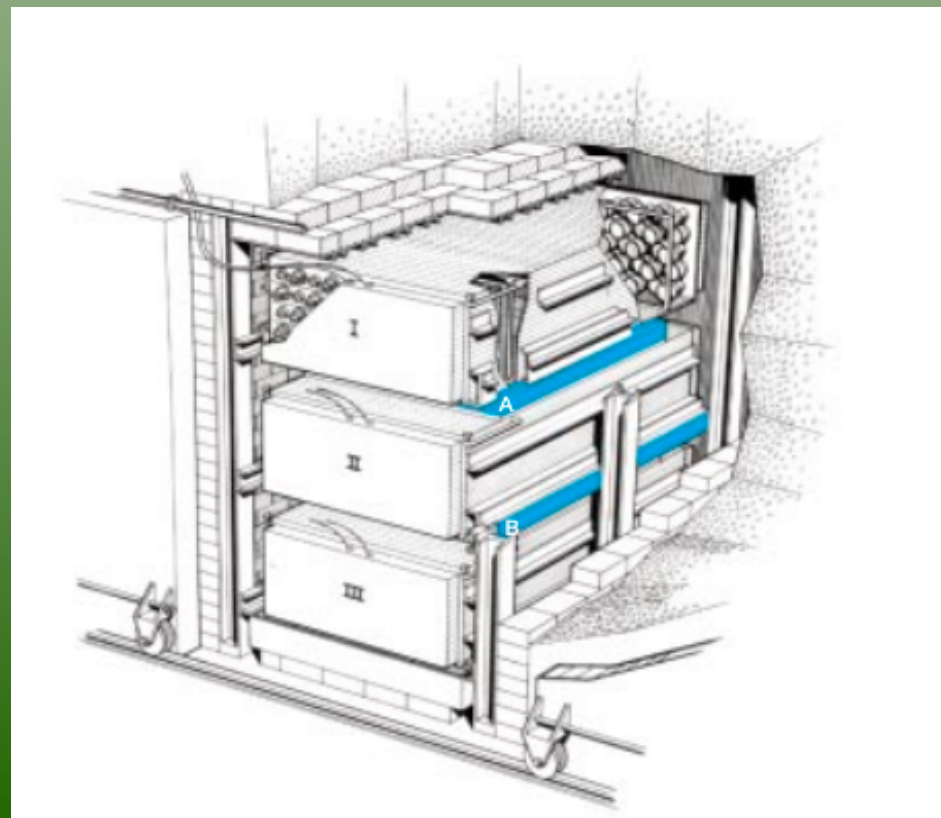


Fred Reines



Clyde Cowan, Jr.

Lots of antineutrinos produced by the Savannah River nuclear reactor



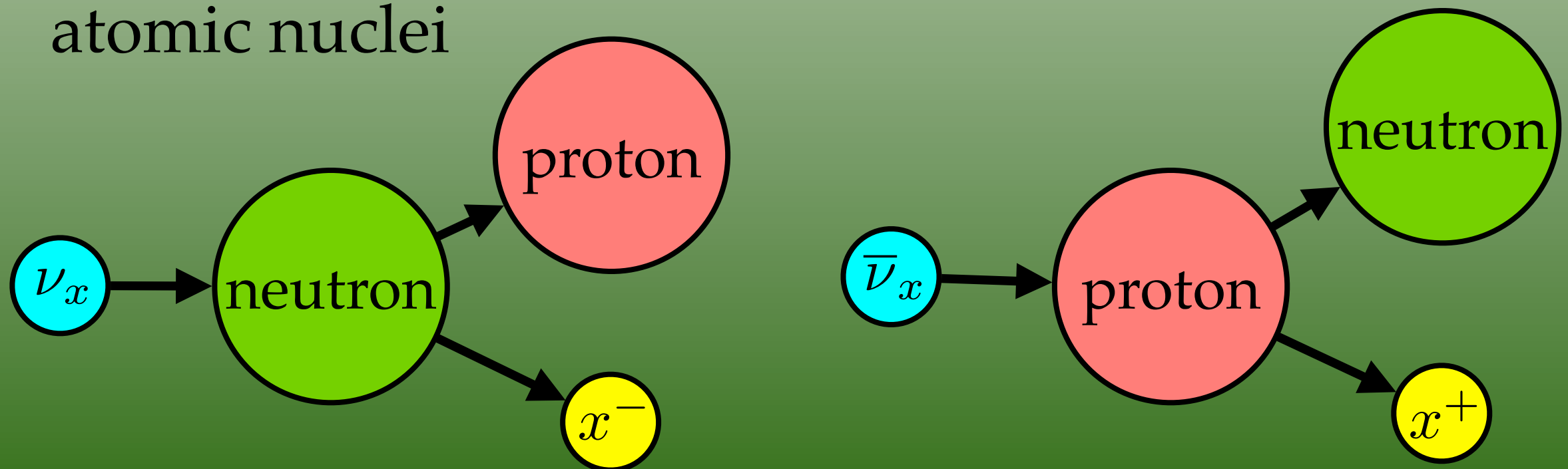
1956: Their experiment detected the products of the neutrino interactions.

Flavors of a very different kind

*Pauli proposed one neutrino, but we have found 3



*Identified by the results of their collisions with atomic nuclei

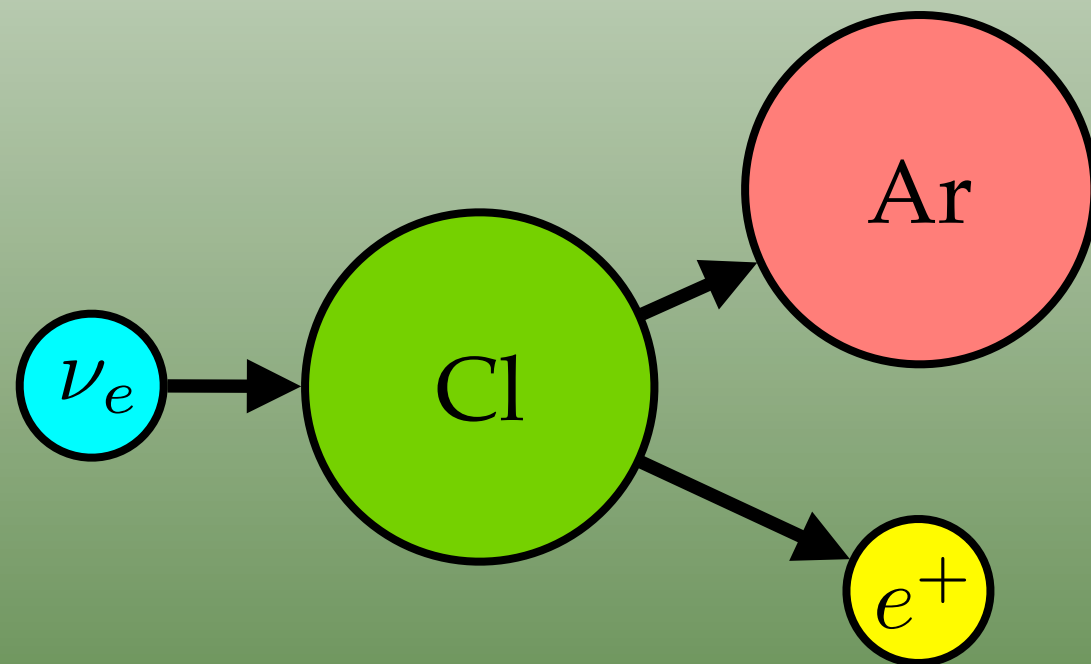


Enter: Raymond Davis

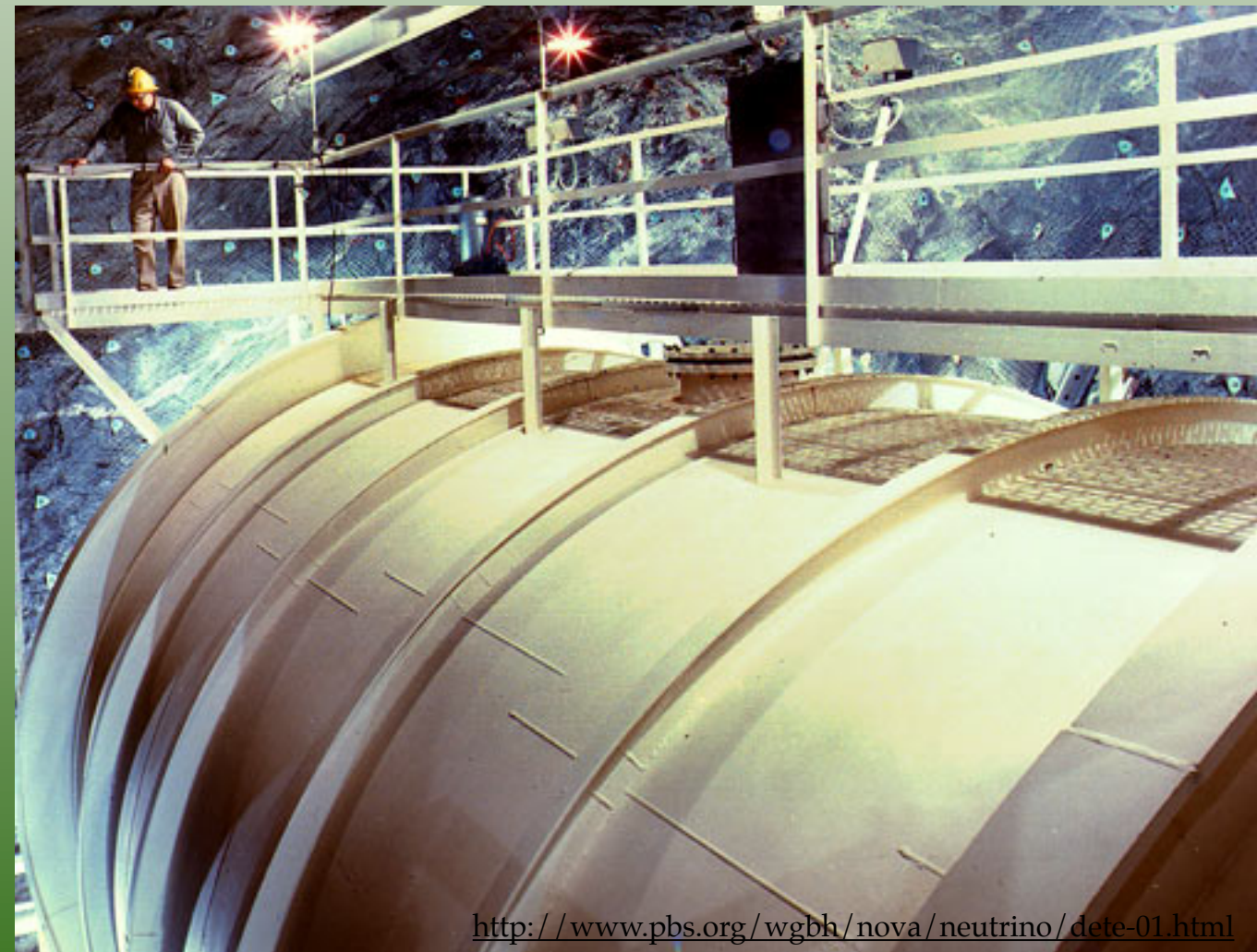
*Beginning in 1968, he used dry cleaning fluid (containing Chlorine) to detect neutrinos from the sun



Image Credit: [Brookhaven National Lab](http://www.brookhaven.gov/).



Found only 1/3 of the expected number of neutrinos!



<http://www.pbs.org/wgbh/nova/neutrino/dete-01.html>

A Problem in the Sun?

- *In *The Songs of Distant Earth* by Arthur C. Clarke, the neutrino deficit is a sign the sun will soon explode
- *Fortunately, the real answer turns out to be a great relief (and even stranger)...
- *Note that Davis' experiment could only detect *one* kind of neutrino



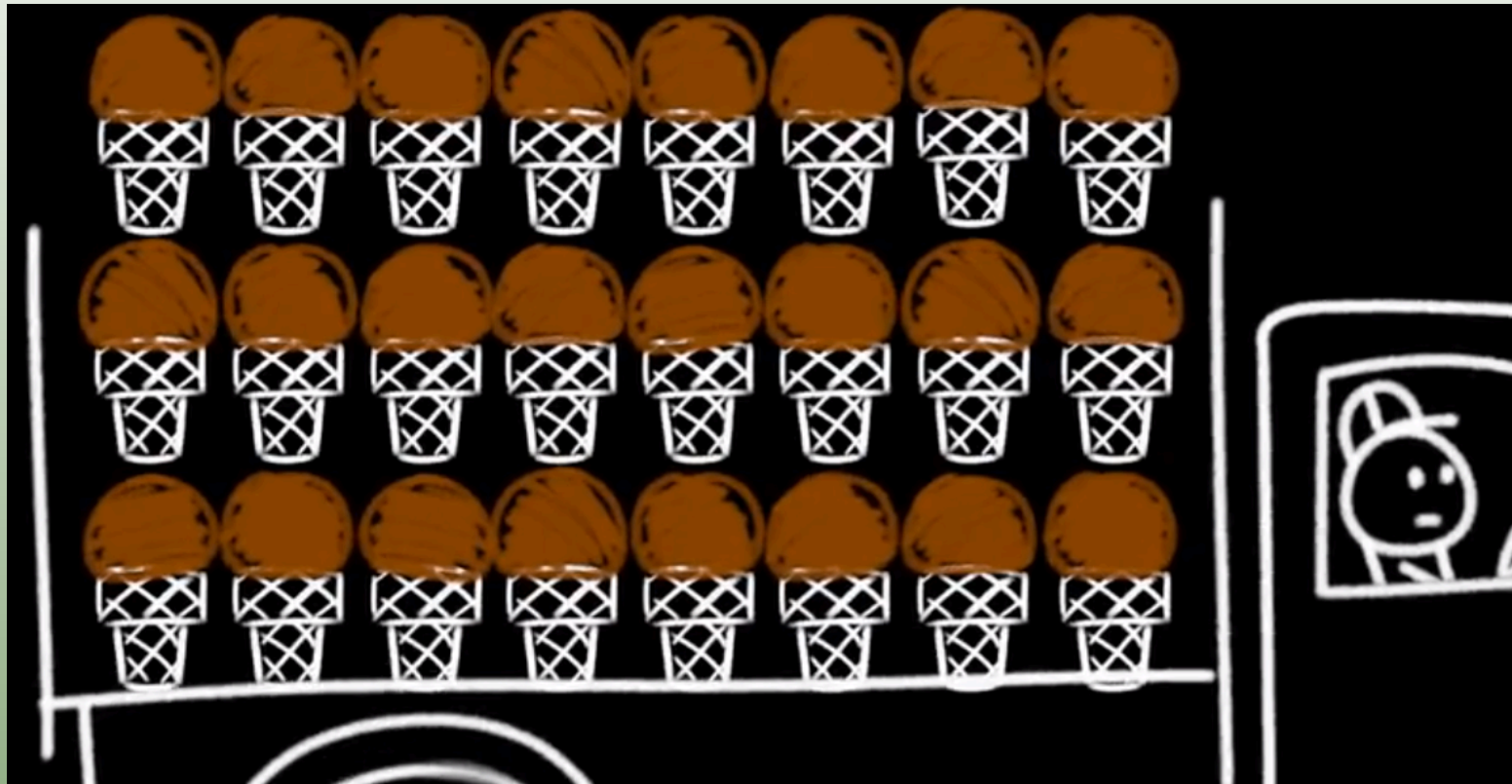
They *What*?!



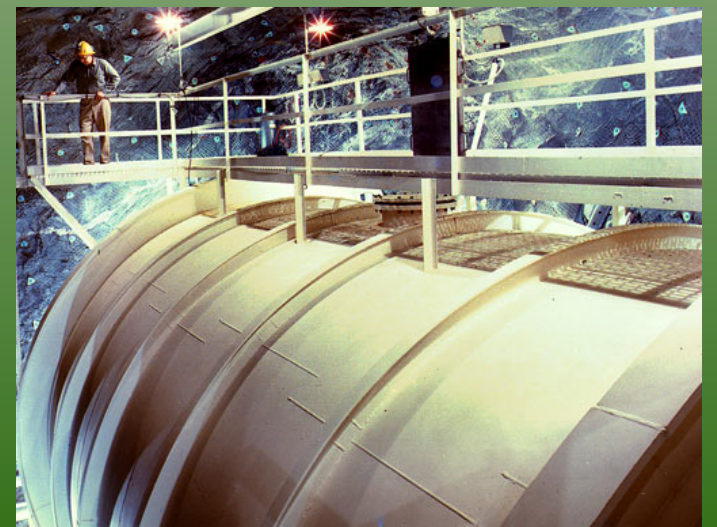
ν_e Source
(The Sun)

Now my own suspicion
is that the Universe is
not only queerer than
we suppose, but queerer
than we *can* suppose." -
J. B. S. Haldane

They *What*?!



ν_e Source
(The Sun)

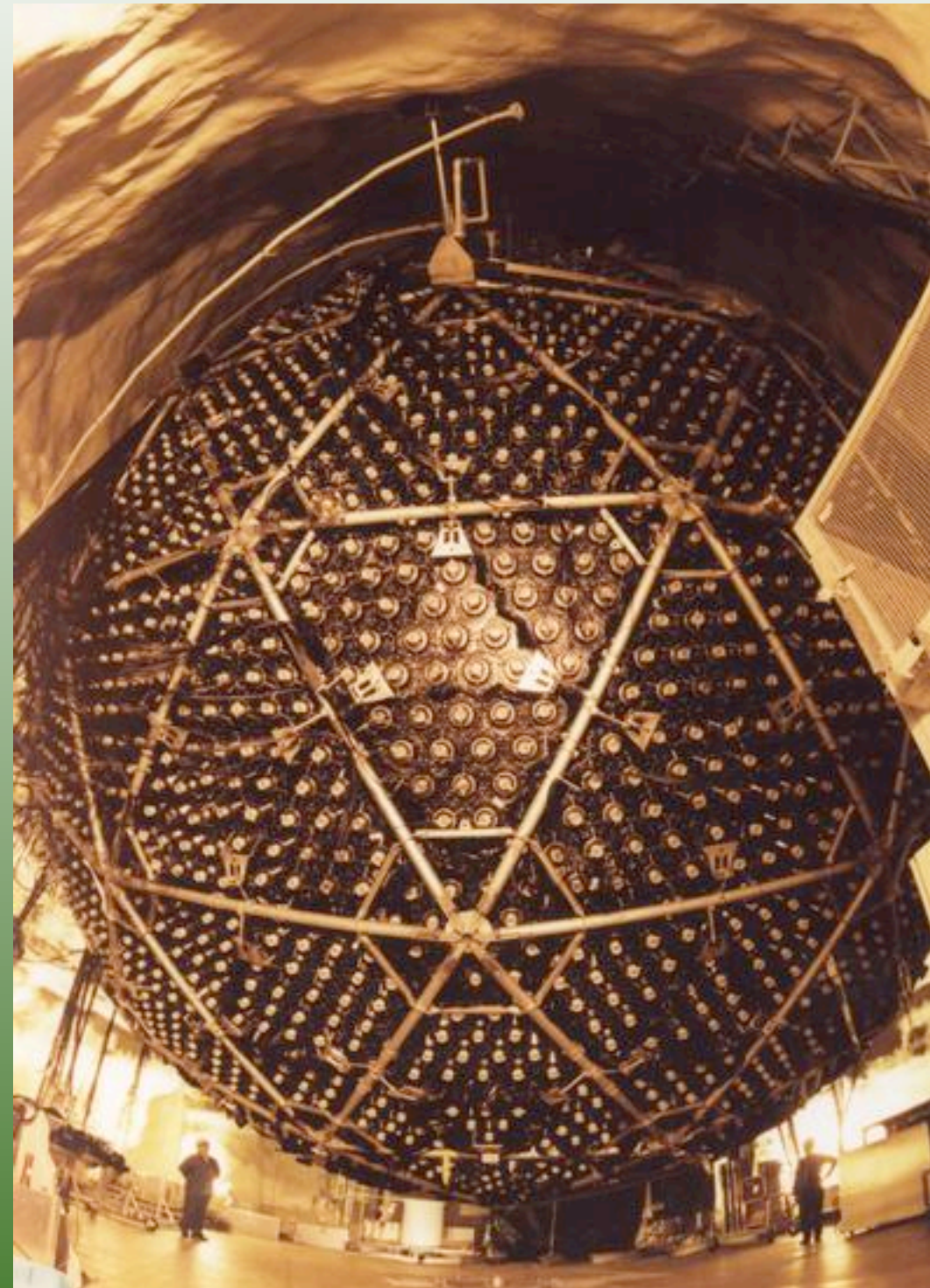


Confirmation...



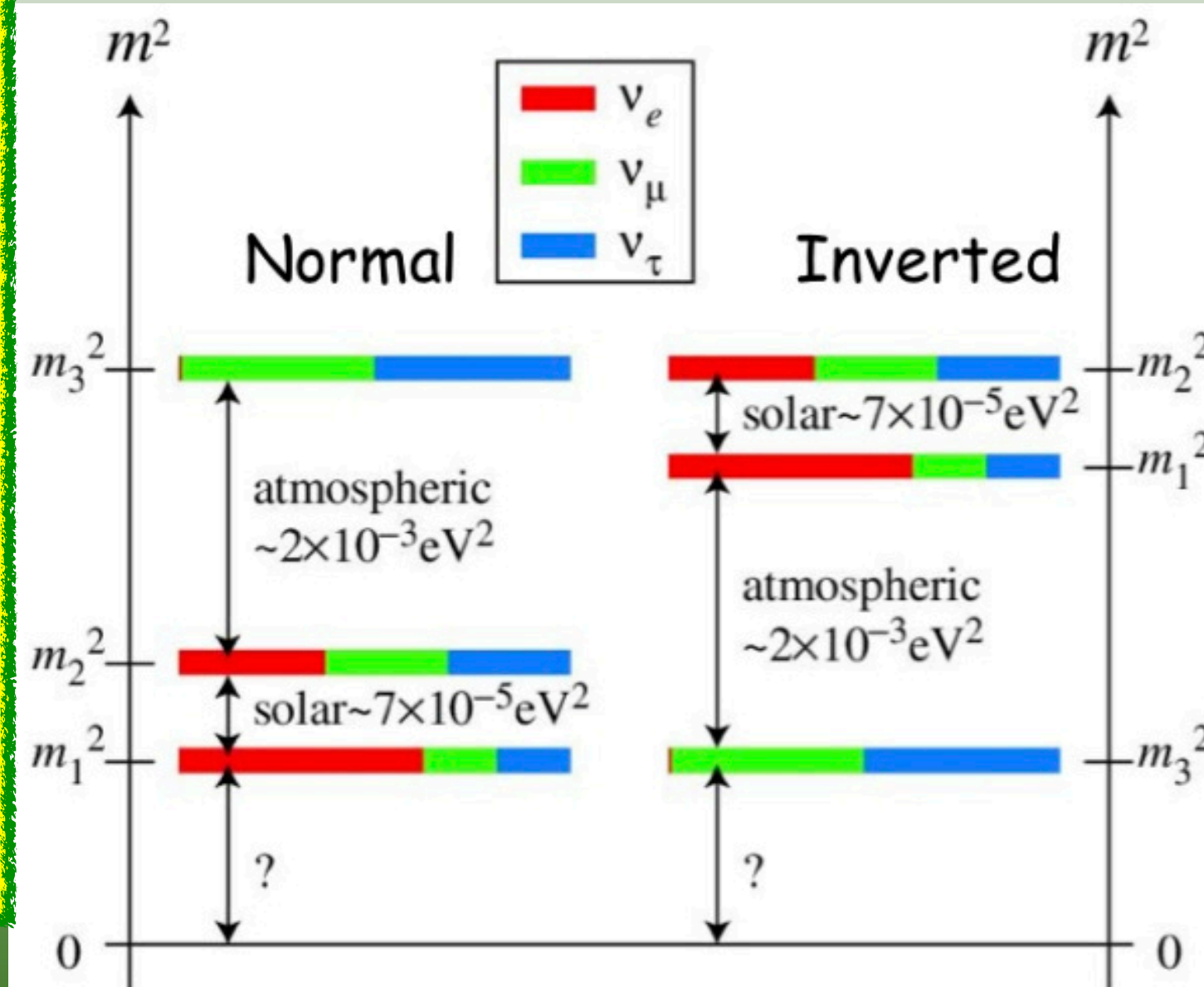
The Sudbury Neutrino Observatory in Canada used heavy water to detect all *three* kinds of neutrinos from the sun.

*In 2001, SNO confirmed that the solar neutrino problem was the result of neutrinos *oscillating* between flavors



Great, now he's speaking German...

What actually propagates through space are ν_1, ν_2, ν_3 , which have definite mass and are mixtures of ν_e, ν_μ, ν_τ

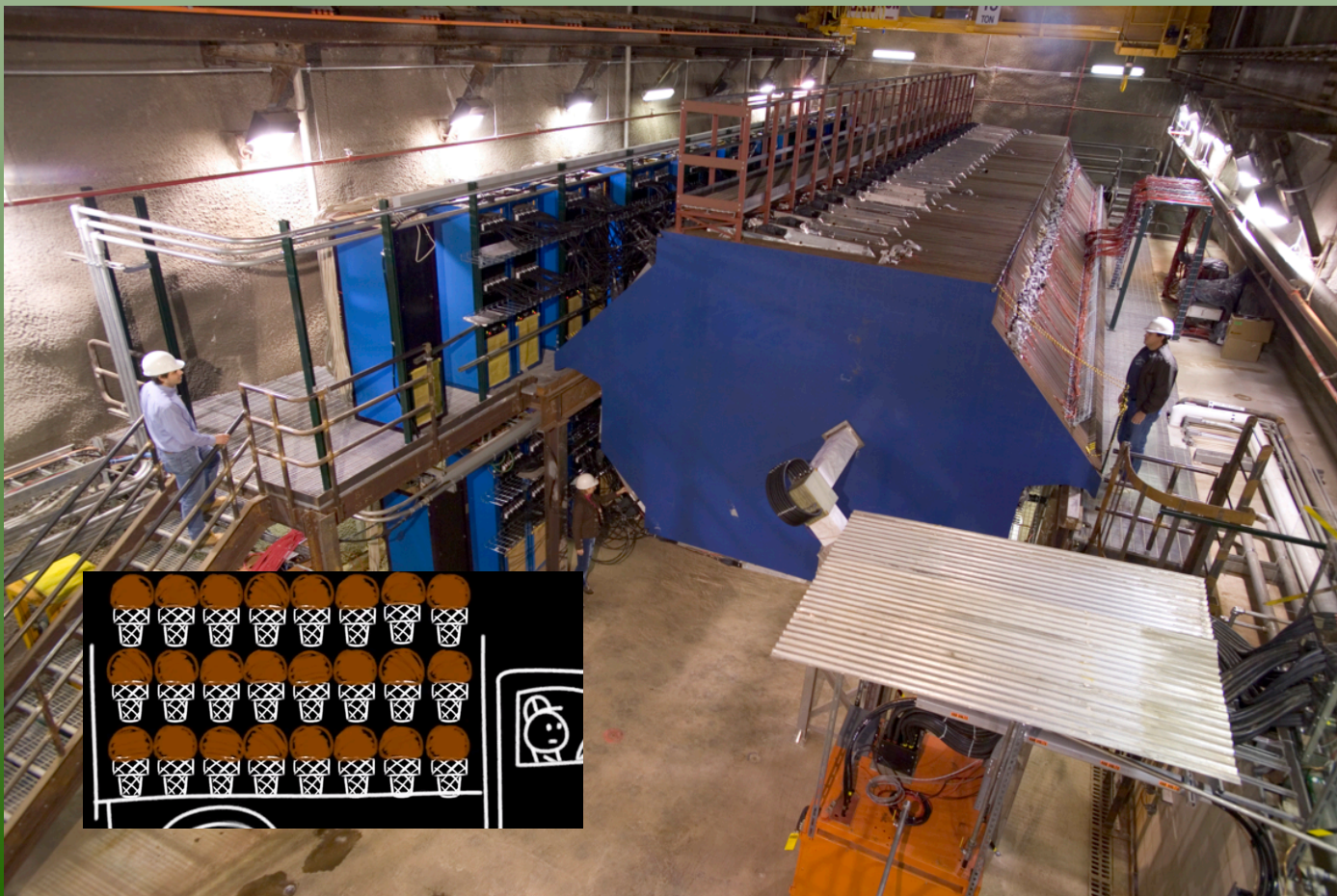
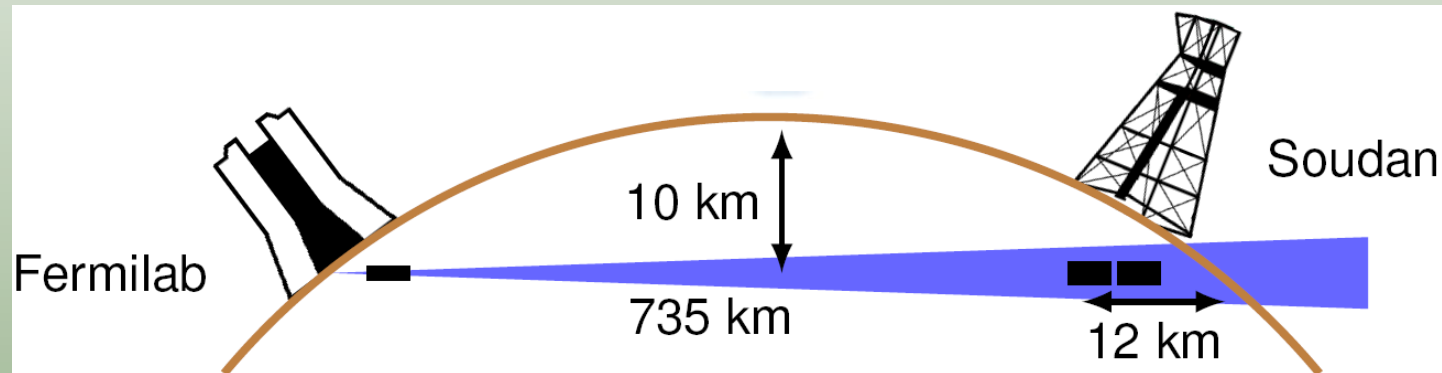


We have measured and are measuring the difference between the masses and the composition of ν_1, ν_2 , and ν_3

<http://neutel11.wordpress.com/2011/03/16/neutrino-mass-models-by-steve-king/>

Right Through the Earth...

*We can also make our own neutrinos



Faster than light?

*Speed = Distance / Time

Connected to the Universe

*The Universe is governed by four interactions

Strong Nuclear

Electromagnetic

Weak Nuclear

Gravity

Neutrinos do not feel these interactions

Neutrinos are the *only* particles to feel *only* this force and gravity.

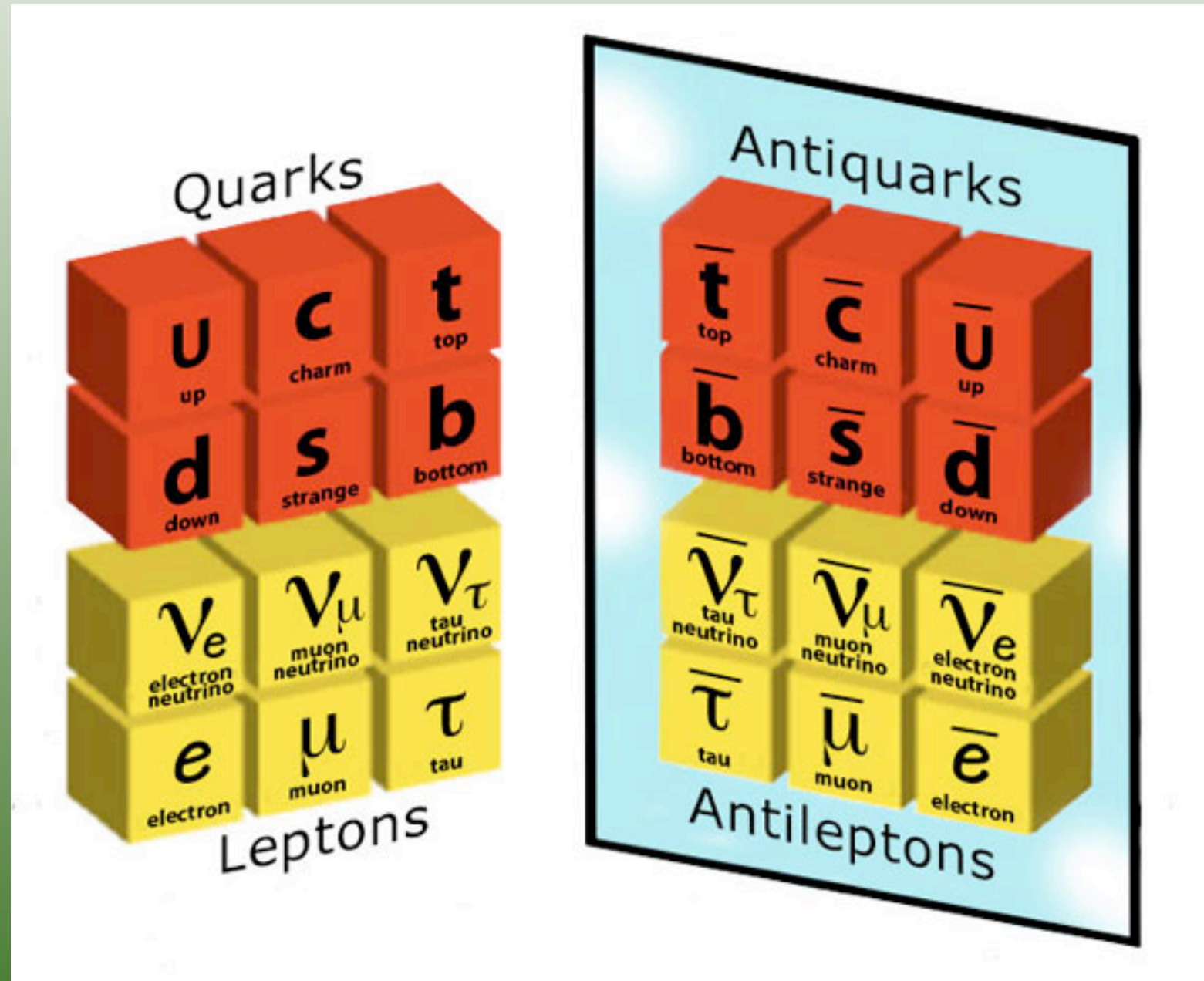
Too weak to matter in particle physics



They are a unique window to understanding this foundational part of our Universe.

CP Violation

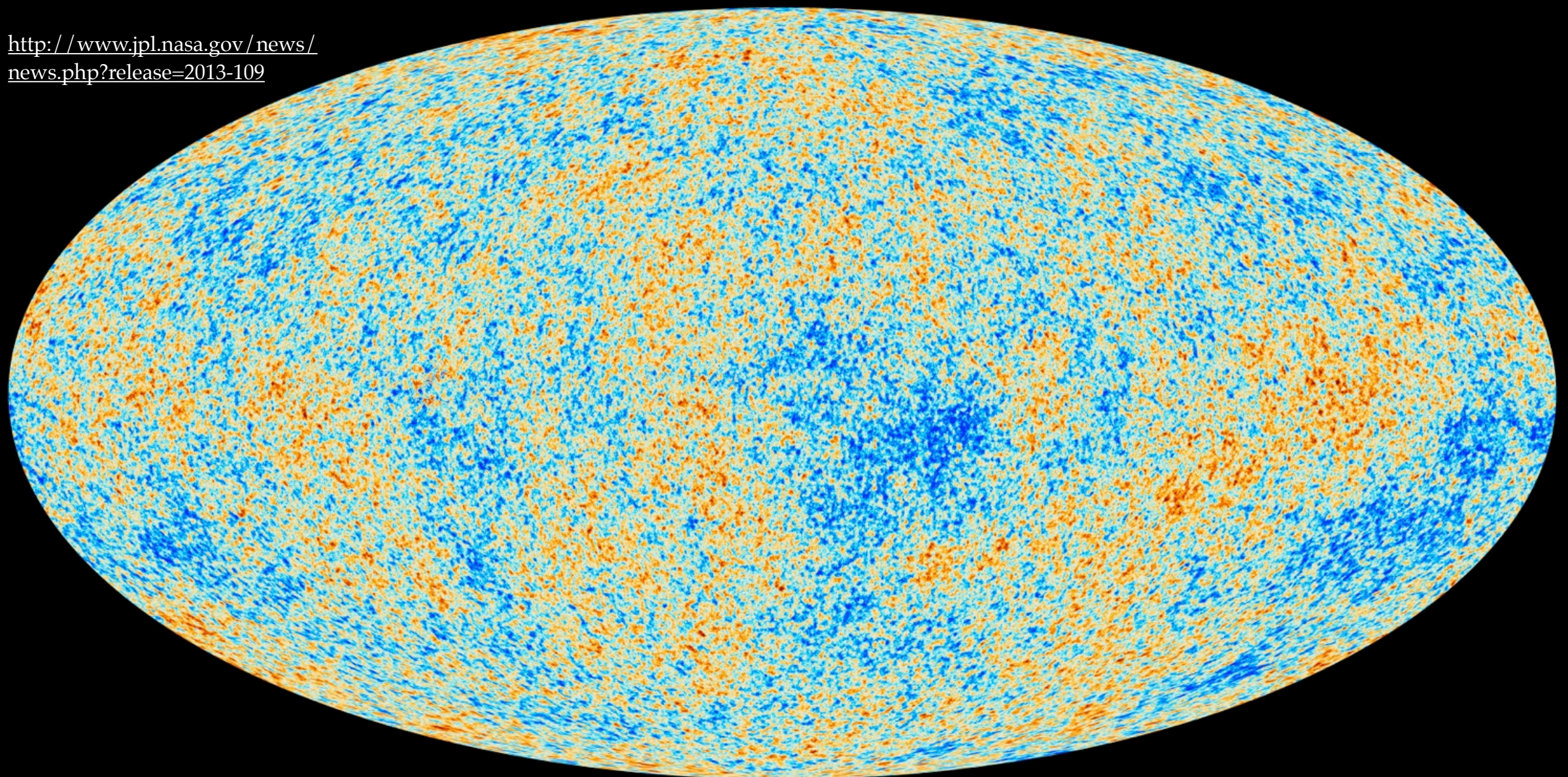
- *We think the big bang produced matter and antimatter in equal quantities.
- *They must behave slightly differently in order to explain our existence



Why Are We (Still) Here?

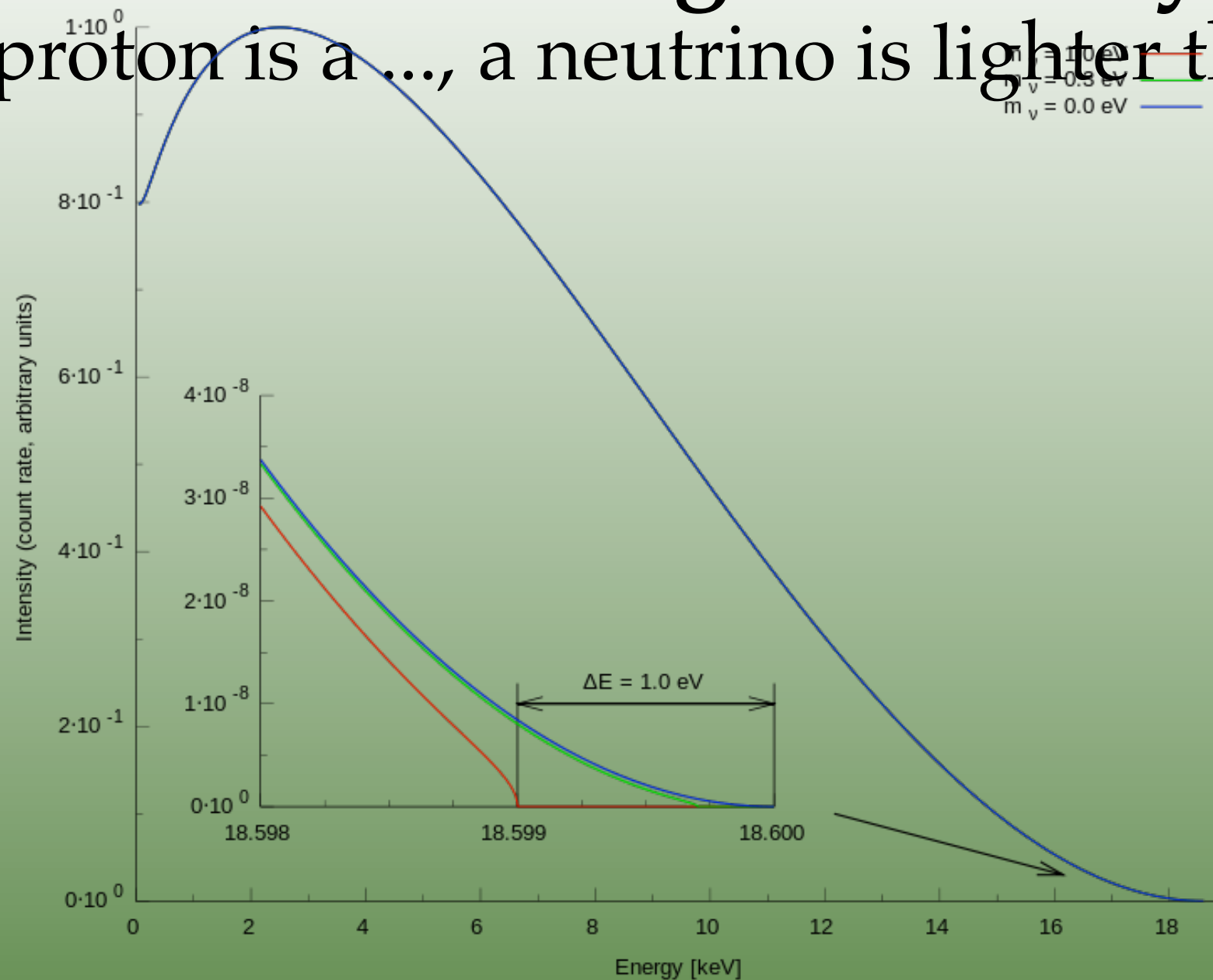
*Antimatter had a slight (1 part in 10 billion) advantage over matter after the big bang. We do not know why. Neutrinos cold hold the answer.

<http://www.jpl.nasa.gov/news/news.php?release=2013-109>



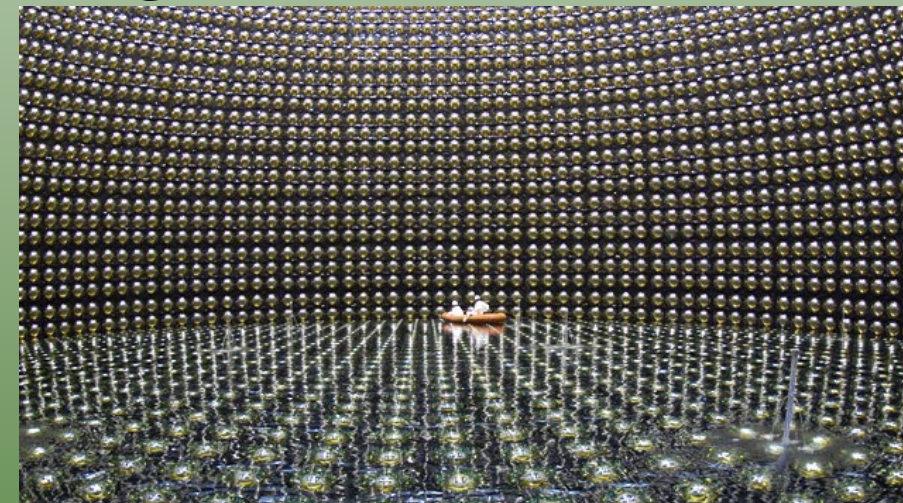
How light are they

*If a proton is a ..., a neutrino is lighter than an ant



Known Unknowns...

- *Is the mass hierarchy “normal” or “inverted”?
- *Do neutrinos violate CP?
 - ★Does this explain the matter dominated Universe?
- *Can we find the Cosmic *neutrino* background?
- *What are the neutrino masses?
- *Why are they so light?
- *How much ν_{μ} is in ν_3 ?
- *Are neutrinos their own antiparticles
- *Are there more than 3 flavors of neutrino?



Unknown Unknowns

Neutrinos could and probably do have many more surprises in store

We do not know what great discoveries await. This is the most exciting part of science!

To those of you who are students, if you become a physicist, you could help answer some of the questions we know how to ask and even those we don't!

Thank You!

The Scientific Method (An Example)

- *Ask a question: *Do brown cows give chocolate milk?*
- *Formulate a hypothesis (testable answer): *Yes! (I like chocolate milk)*
- *Make a prediction: *If I milk a brown cow, I will get chocolate milk*
- *Test the prediction: *Find the nearest brown dairy cow...*



*Verify, modify, or reject hypothesis



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